Department of Physics,
Medical Physics and Radiation Research

HIRSLANDEN
Radiotherapie Hirslanden

# Development of a Single Ion Detector for Characterization of the Track Strucuture of Ionizing Radiation


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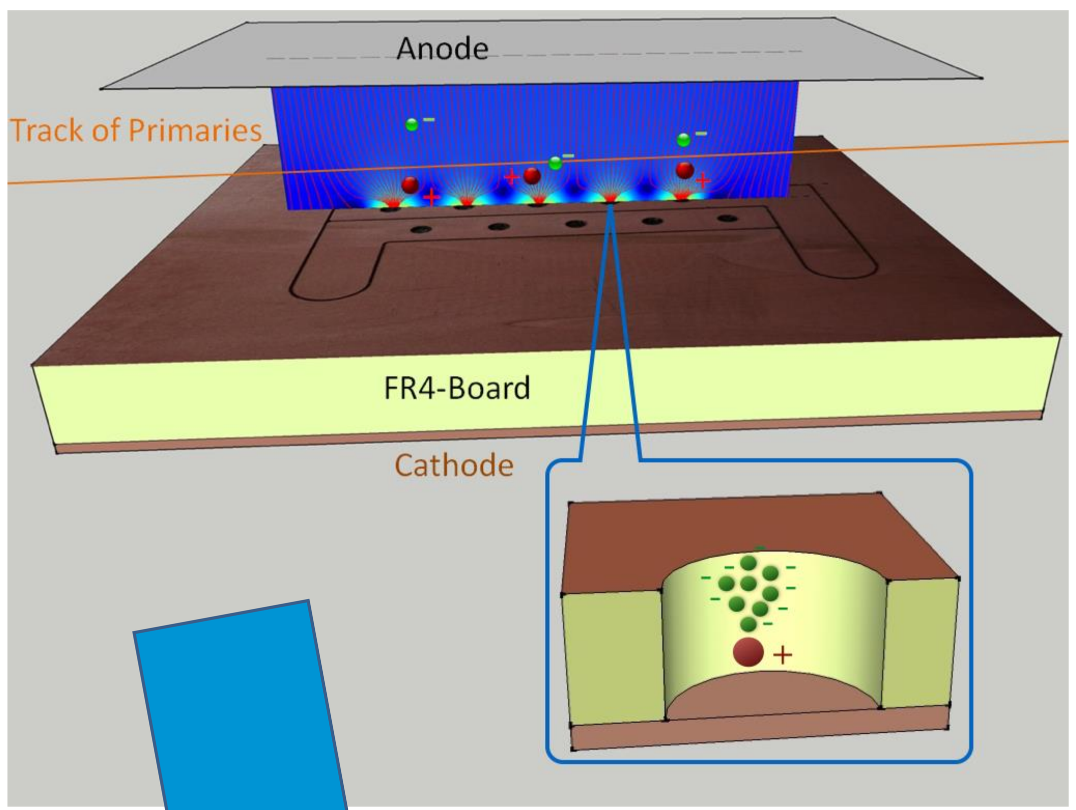
## Development of a Nanodosimeter Detector




Ionizations are produced by radiation in a volume of low-pressure gas. The positive ions drift into holes of millimetric dimensions drilled in a dielectric board. Here, ions are accelerated by a strong restricted field and produce impact-ionization that develops into a discharge inducing a signal in the readout electrode (top of the board).

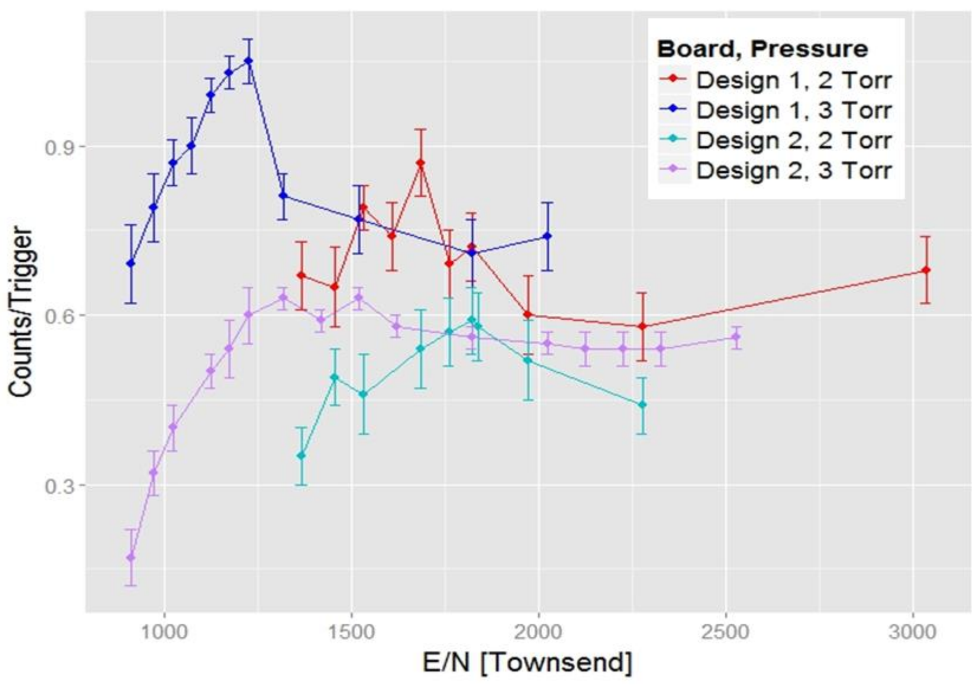
### Introduction

Absorbed dose times the relative biological effect (RBE) is inadequate to describe biological outcomes for proton and ion beams. It was shown that clusters of multiple ionizations within 2 – 3 nm correlate well with the yield of double-strand breaks in DNA. Furthermore, it is assumed that the reason for the higher biological effectiveness of high-LET compared to low-LET radiation is due to the differences in their track structure. Experimental characterization of ionization patterns on the nanometric scale could be used for assessing biological radiation quality.

### A Compact Track Imaging Detector

This resistive thick-GEM like detector combines the operational principle of gas avalanche multiplication within holes with an electrode of high-bulk resistivity as used in resistive plate chambers.

The ion detection efficiency is enhanced by increasing the thick-GEM thickness up to 1 cm, consequently increasing the chance for low energy ions to produce impact ionization. Registering the coordinates of the hole position and using the time difference between signals as information on the third dimension, the 3D spatial distribution of the initial ionization events can be reconstructed. A scaling procedure for which measured cluster size distributions in a low pressure gas become equivalent to cluster size distributions within a nanometric target in liquid water is used.




Mean number of detector counts per primary particle measured as a function of the restricted field E/N. Larger efficiency is obtained for design 1.
Lower efficiency of design 2 board is ascribed to large cathode discharge area and interplay of adjacent holes.

### Detector Characterization

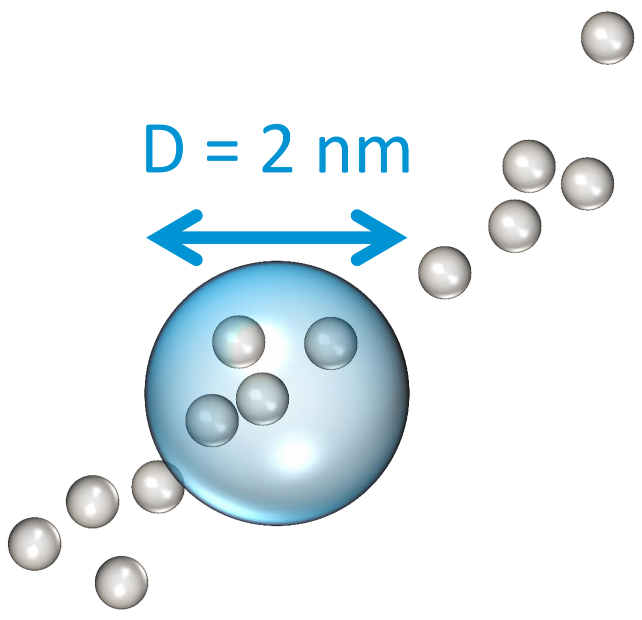
Two board designs with different hole pitch (6 and 4 mm) were tested with a $^{241}$Am source.

Measurements with a microbeam provided by PTB (Germany), were performed with the design 1 board. The mean counts per primary particle for a 20 MeV alpha microbeam was larger when the beam was centered above the holes. Similar results were obtained for 10 MeV protons. This is an indication that the ion collection efficiency is larger above the holes and that the ion focusing into the holes due to the electric field is smaller than expected from simulations.

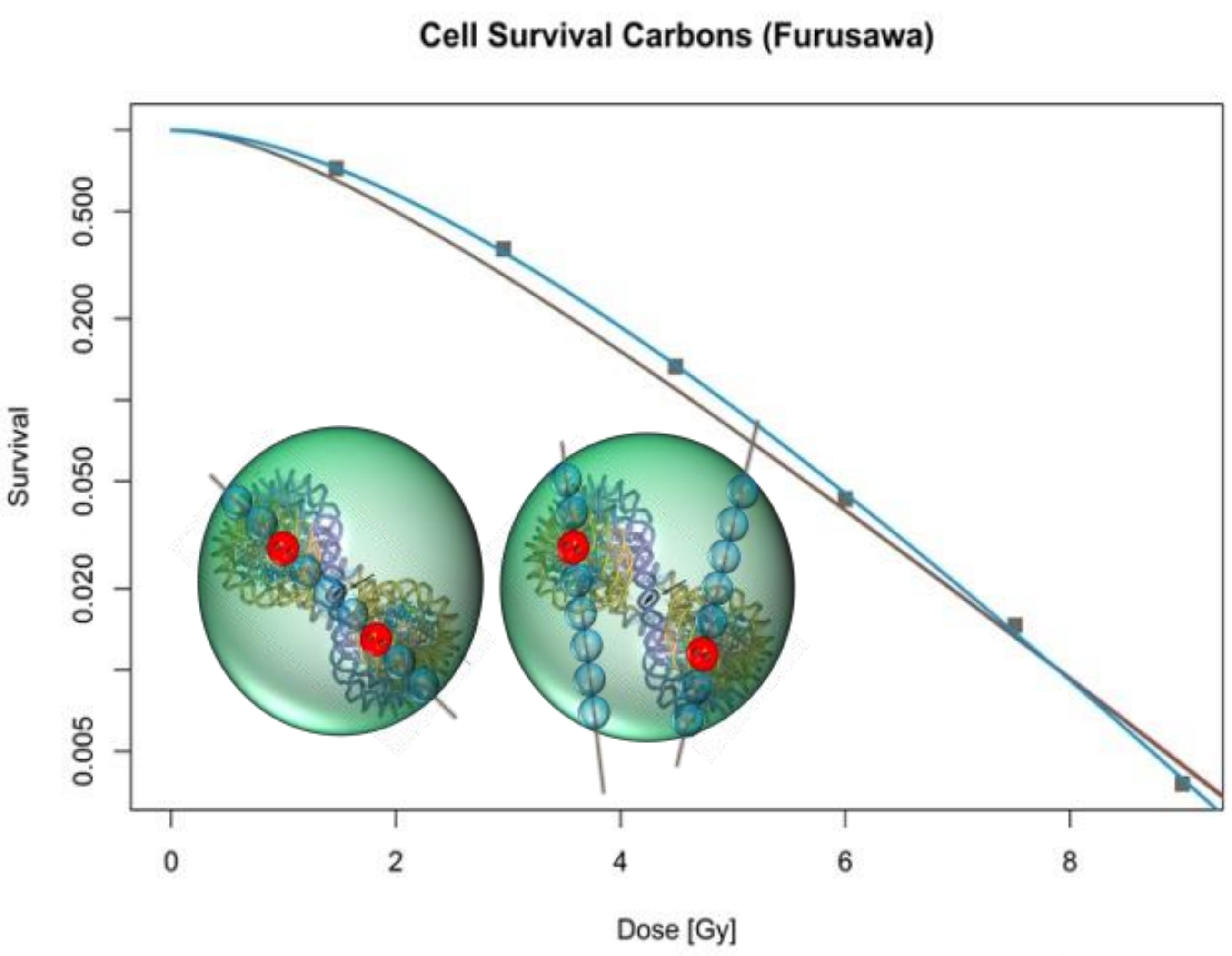
Moreover, the mean counts/trigger is decreasing for increasing primary rate which suggests that the detector dead time is of the order of milliseconds.

Dead time could be due to long cathode recharge time determined by the resistivity of the cathode.

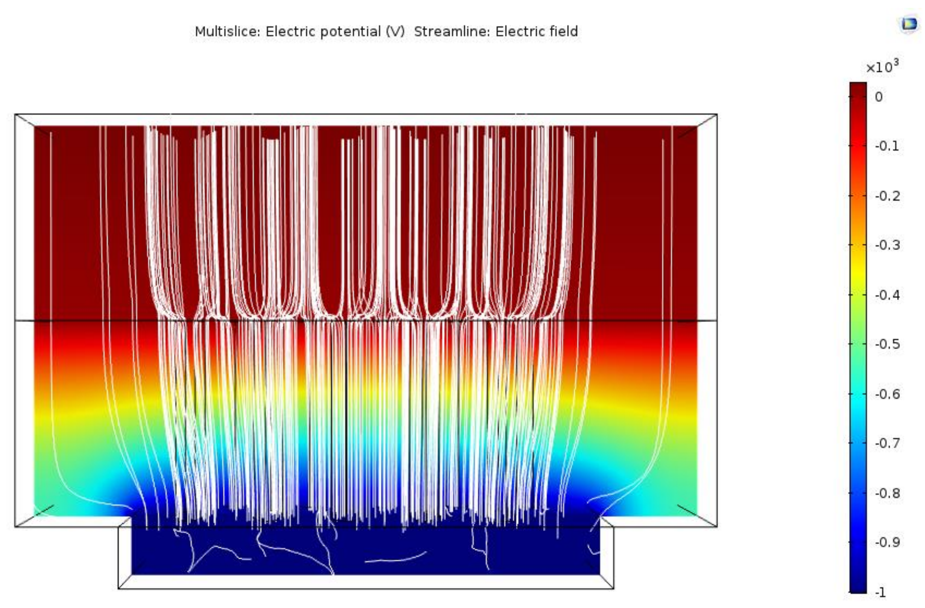
## Monte Carlo Simulations




## Nanodosimetric Based Cell Survival Model

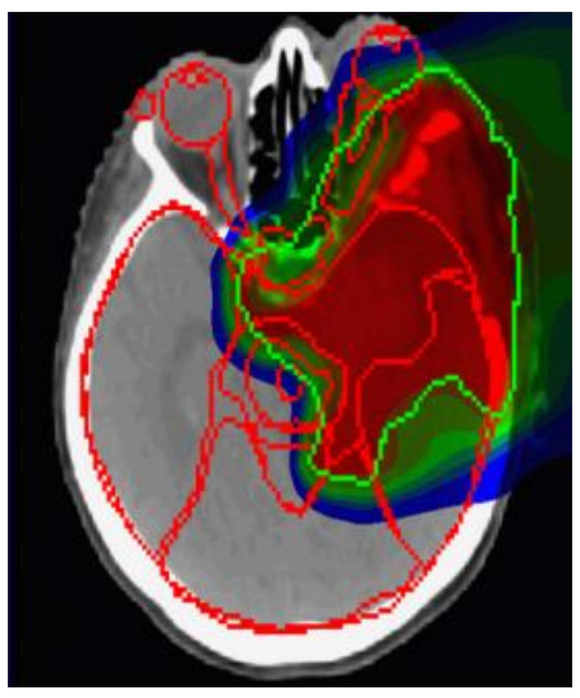



Furthermore, charge-up of the dielectric walls could affect the recovery time of the accelerating electric field and thus the detection efficiency. Slightly conductive materials as ZrO2 will be tested.



### Track-Event Theory

The linear-quadratic model dominates the description of cell survival after irradiation because of its simplicity and robustness, even though it is inaccurate for large doses and lacks a mechanistic explanation. To overcome these shortcomings of the linear-quadratic model and without losing the simplicity, the track-event theory, a mechanistic cell survival model, was investigated. The parameters of the track-event theory are derived from measurable nanodosimetric quantities which take the track-structure into account. Radiation induced damages are predominantly produced in the DNA or its vicinity and therefore it is evident that the track structure plays a key-role in the biological effectiveness of a particular radiation. It is assumed that the track-structure is more important for high-LET particles. The new model was fitted to experimental data for charged particles and compared to the linear-quadratic model. The results show that the track-event theory fits the experimental data as well as the linear-quadratic model.



### Optimize Treatment Plans

Similarly to the concept of "LET-painting", one might consider using nanodosimetric quantities to further optimize already classically calculated treatment plans by the means of applying conditions and/or constraints on a nanodosimetric quantity.

Ultimately, in the future it could be investigated whether the concept of (RBE-weighted) absorbed dose might be replaced altogether by a nanodosimetric and measurable quantity such as *fluence-weighted* F2.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